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THE

AMERICAN NATURALIST

VOL. XXVI. November, 1892. 311

HEREDITY OF ACQUIRED CHARACTERS.*

BY DR. MANLY MILES.

The remarkable progress of science for nearly half a century must be largely attributed to the general recognition and extended applications of the laws of *evolution* and the *conservation of energy.*

In the biological departments of science, evolution has had a predominant influence in suggesting lines of investigation, and in the interpretation of results, while the significance of energy as a factor in all organic processes has not been as fully recognized.

In both vegetable and animal physiology there is a growing tendency to look upon the collocations of matter as incidents, or manifestations of the transformations of energy, and the changes taking place in vital activities are conveniently expressed by the general term *metabolism* that includes the dynamic as well as the material factors, which cannot be separately considered, from the complexity of their intimate relations. Even in the processes of nutrition it appears that the demands for the material elements of tissues are limited, while the expenditures of energy in the constructive processes and their collateral functions are enormous.

It is not my purpose to attempt a general discussion of the conservation of energy as a factor in biological activities, but

*(Read before Section of Biology, A. A. A. S., Aug. 19th, 1892.)

to call attention to some of the processes of nutrition with reference to their import as causes of variation, or the origin of new characters that may be made available through natural selection in the evolution of plants and animals.

The inheritance of acquired characters has been called in question by Weismann, and positively denied by those who accept his theory of the continuity of the germ plasma as originally formulated, and all inheritable variations are assumed to be the result of fortuitous changes in the reproductive germs.

The advocates of this theory confine their attention almost exclusively to gross morphological characters which have been developed and fixed through an accumulation of numerous slight variations for many generations, and ask for direct proof of the complete transformation of these stable characters by changes in the habits of a single individual, while the abundant evidence of physiological, or functional changes in nutritive processes which must be considered as the necessary precursors, and probable causes, of morphological variations, is claimed to be inadmissible.

The processes of metabolism in the nutrition of plants and animals, as now interpreted by physiologists, furnish a rational explanation of the manner in which the reproductive germs may be influenced by functional adaptations of organisms to their environment, which are admitted to be causes of individual variations; and theories of heredity and evolution in which these physiological factors are not taken into consideration cannot be accepted as a satisfactory solution of the problems presented.

Omitting subordinate details which represent the separate links in the chain of events, the processes of nutrition may be summarized in general terms as follows: In plants the chemical elements, and binary compounds on which they feed, are built up by successive steps of increasing complexity and instability into protoplasm, with a storing of the energy made use of in the constructive process, which is derived from the heat and light of the sun. The constructive processes are expressed by the term anabolism, and the products of the different upward steps are called anastates.

Protoplasm the most complex and unstable of organic substances is the summit of the ascending steps of the constructive processes, and katabolism, which represents the succeeding downward steps of destructive metabolism, then follows, and its products, or katastates, are starch, cellulose, proteids, &c., or what we recognize as the proximate constituents and tissues of plants.

The heat developed in the nutrition of plants is also a product of katabolism, and it represents the difference between the potential energy of the protoplasm, and the potential energy of the other katastates formed from it. This is not however sufficient to enable the plants to maintain an independent temperature, as it is rapidly dissipated by radiation from the extended surface of the foliage, and a large amount is used in vaporizing the water exhaled by the leaves. An approximate quantitative estimate of the energy expended in exhalation was given in a paper read before section I, last year, and published in the May number of the *Popular Science Monthly.*

From their greater complexity the more highly differentiated processes of nutrition in animals are not so readily traced, but the general course and results of metabolism, broadly stated, are essentially the same as obtain in plants. The food of animals consists of the proximate constituents of plants, or the katastates of plant metabolism, and with the exception of oxygen introduced in the process of respiration, they are unable to assimilate the simpler elements on which plants feed.

The first demand of the animal economy is for energy to be used in the constructive processes, and this is derived exclusively from the stored energy of the organic substances of their food through the destructive metabolism involved in the processes of digestion. The proteids, fats and carbohydrates of the food of animals are not directly converted into animal proteids and fats, but the evidence indicates, as pointed out by Dr. Foster, that they are reduced almost to their original elements and then reconstructed through the agency of animal protoplasm. In no other way can the energy required in animal nutrition be obtained, and as an incident of the destructive metabolism of foods in the process of digestion the materials for the constructive process are provided for immediate use in a simpler form than that in which they were ingested.

In general terms we may then say that the anabolic processes of animal nutrition consist in utilizing the liberated energy in building these disintegrated food constituents into protoplasm, with a storing of the energy as an essential condition of its constitution; and the animal proteids and fats, and in fact the tissues generally are the katastates of its destructive metabolism, that contain less potential energy than the protoplasm from which they are formed; the difference appearing as animal heat, which is supplemented by the destructive metabolism of the tissues involved in their functional activity, or what is popularly called the wear and tear of the system. As in plants, protoplasm is the summit, or highest phase of the anabolic activities, and tissue building must be looked upon as a result of its katabolic transformations.

In the higher animals the nutritive processes are more complex, and the number of upward and downward steps of metabolism is increased through the elaboration of a common nutritive fluid, the blood; but the sum and final outcome of the anabolic and katabolic changes are essentially the same as in the simpler organisms. Energy is used and stored up in the anabolic or constructive processes, and liberated again as animal heat in the "simultaneous and successive" katabolic processes which result in the formation of the various tissues.

Protoplasm is no longer looked upon as a substance of a definite chemical composition and constitution, as it must vary widely in its specific properties in the different species of plants and animals, and even in the different organs of the same animal, and the varieties of protoplasm are therefore innumerable.

In addition to these variations arising from the characteristics of protoplasm in different species, and in their highly differentiated organs, the anastates representing the successive steps of its elaboration, and the katastates resulting from its destructive metabolism in the same individual, must vary with the ever changing conditions of the environment, and the functional activity of every part of the organism. Individual variations from the prevailing type of the group, or family, are then readily accounted for by a disturbance in the symmetrical balance of the metabolism of the different organs of the body, by prevailing habits, or changes in the environment and conditions of food supply.

In the phases of life from the embryo to the final decline of the bodily powers, there are changes in the relative predominance of anabolic and katabolic activities that we should not fail to notice.

In Dr. Minot's interesting address at Indianapolis " On Certain Phenomena of Growing Old, " the sequence of mutations in metabolic activities in the life of the individal were clearly shown. The greater activity of the nutritive functions in youth, and their gradual decline to maturity and old age were strikingly illustrated by an instructive series of statistical diagrams. It was also shown " that with the increasing development of the organism and its advance in age, we find an increase in the amount of protoplasm. " This apparently conflicts with the conception of protoplasm as the physical basis of life, and the most plausible inference from these facts, as suggested by Dr. Minot, was that " the development of protoplasm is the cause of the loss of power of growth, " and that " protoplasm was the physical basis of advancing decrepitude. "

A less obvious, but more satisfactory, explanation is furnished in the outline of the processes of nutrition already presented. It is evident that protoplasm is but a way station, as it were, in the development of tissues, and its destructive metabolism is an indispensable condition of growth, and increase of organic substance. The greatest activity of the katabolic phases of metabolism take place in the embryo and youth, and they then keep pace with the anabolic, or constructive processes of the organism, so that the protoplasm elaborated is used in tissue building as fast as it is formed. When maturity is reached the demand for new materials in growth ceases, the wear and tear of the system is diminished with less intense demands for the processes of repair. With this falling off in the requirements of the organism for katabolic products including energy, anabolism predominates and protoplasm is allowed to accumulate in the different organs from the check to destructive metabolism arising from the general decline of vital activities.

The hypothesis that the germ plasma, or the reproductive granules it contains, are immortal and entirely independent of the body-plasma, on which is based the assumption that acquired characters cannot be transmitted, appears to be in direct conflict with these physiological laws of nutrition. The protoplasm of the body presents, as we have seen, many differentiated varieties, adapted to the specific function of each organ, and its katastates differ accordingly. The various glandular secretions, the products of nervous and muscular activities, the numerous excretory products, and even the germ cells so far as their molecular structure is concerned must be considered as katastates of the protean varieties of protoplasm. The so-called body plasma must then be looked upon as made up of many differentiated subdivisions, in genetic relations with many katabolic products, all of which are correlated, through vital activities, to act in harmony to serve the entity we recognize as the individual.

The differentiation of a germ-plasma especially concerned in the function of reproduction must be accepted as a physiological factor of the first importance, but we are not warranted in assuming that it is exempt from the metabolic transformations that characterize other living substances.

Herbert Spencer defines life as " the continuous adjustment of internal relations to external relations;" and Dr. Foster expresses substantially the same conception in defining living substance as " not a thing or body of a particular chemical composition, but matter undergoing a series of changes." These definitions fairly represent our present knowledge of vital activities. Metabolism with its "simultaneous and successive" phases of anabolic and katabolic transformations of matter and energy, is admitted to be an essential condition of life in all tissues and elements of the body.

As living matter the germ plasma must be continually undergoing metabolic changes in adjusting its internal relations to its external relations with the body plasma, and interchanges of matter and energy must be involved in its increase and growth.

These constant changes in the substance of the germ cells were not recognized in the original hypothesis of the continuity of the germ plasma. As formulated by Weismann "heredity is brought about by the transference from one generation to another of *a substance with a definite chemical, and above all molecular constitution*," which he called germ plasma, and assumed that it possesses a "highly complex structure conferring upon it the power of developing into a complex organism," and heredity was further explained, "by supposing that in each ontogeny a part of the specific germ plasma contained in the parent egg-cell, is not used up in the construction of the body of the offspring, *but is preserved unchanged for the formation of the germ cells of the following generation.*" Again he says, "the germ plasm, or idioplasm of the germ cell, (if this latter term be preferred), certainly possesses an *exceedingly complex minute structure, but it is nevertheless a substance of extreme stability, for it absorbs nourishment and grows enormously without the least change in its complex molecular structure.*" It is difficult to understand how a living substance undergoing constant metabolic changes can be "a substance of extreme stability," or how it can "grow enormously without the least change in its complex molecular structure."

This assumed stability of molecular structure, and definite chemical composition of the germ cells appeared to be necessary to give plausibility to the claim of immortality, and the further assumption of the non-inheritance of acquired characters. The transmission of a definite, stable, self-propagating substance from one generation to another, uninfluenced by the body plasma, has, in fact, been the shibboleth of those who deny the transmission of acquired characters, but Weismann himself has retreated from this stronghold of his theory as he found it untenable.

In reply to the criticism of Prof. Vines that it was "absurd to say that an immortal substance can be converted into a mortal substance," Prof. Weismann without hesitation abandons the conception of molecular stability in the germ plasma, and presents his theory of heredity in a new form, that is more in accordance with physiological laws, and at the same time appears to be fatal to the assumptions made by his followers. He says, "does not life here as elsewhere depend on metabolism—that is to say a constant change of material? And what is it then which is immortal? *Clearly not the substance* but only a definite form of activity,"—"*An immortal unalterable living substance does not exist but only immortal forms of activity of organized matter.*" The material continuity of the germ plasma is therefore discarded and replaced with the conception of *a mode of motion* manifest in matter that is continually undergoing metabolic changes.

As the complex molecular substance of the germ plasma is brought into intimate relations with the metabolism of the body plasma through its own metabolic activities, we can readily perceive how acquired habits of the organism in modifying the general and special metabolism of the body must also have an influence on the substance of the germ cells, and through their constantly changing substance on the forms of activity, or modes of motion, that are transmitted from one generation to another in accordance with the new theory. It is then evident that the assumed independence of the germ cells of all influence from the surrounding body plasma, that is relied upon to prove the non-inheritance of acquired characters, derives no support from the present conditions of physiological science.

There are many functional variations in the activities of the different organs of the body that can only be attributed to changes in the environment and food supply in connection with the habits of the individual, and they are so clearly defined and of such frequent occurrence that it seems to be unnecessary to assume fortuitous variations in the germ cells as the sole factors for natural selection to act upon. In order to evolve two adult forms that are precisely alike in every detail, from two germs with the same identical qualities and tendencies, there must be in each case the same metabolic activity of every part of the system, giving rise to the same series of anastates in the constructive processes of every organ, and the same series of katastates in destructive metabolism, throughout the entire period of growth, which would of course rarely occur from a lack of uniformity in the surrounding conditions of the two individuals.

Individual variations, which are so frequently observed, are then readily accounted for, and there are no physiological reasons for the assumption that the metabolic bias of the organism which gives rise to them, does not likewise have an influence on the germ cells.

The non-appearance of an acquired habit, or peculiarity of the organism in the next generation, cannot be accepted as evidence that it has not been potentially transmitted. The known facts of atavism show that an inherited peculiarity of the organism may be obscured for several generations by other characters, and then reassert itself with all its original intensity. The established family characters, and the acquired habit or peculiarity, of the individual, represent antagonistic factors, and their relative intensity in connection with conditions of development must determine which is to dominate in the offspring.

The transmission of a character, in the first place, should not be manifest in a direct reproduction of the morphological peculiarity, but it must consist in a habit of the organism that leads to the development of the peculiarity in the offspring under favorable conditions for its exercise. The failure of the effects of injuries or mutilations to make their appearance in the offspring cannot be admitted as evidence to prove the non-inheritance of acquired characters, as the physiological activities of the system that are required to produce the morphological peculiarity have not been established, and there can be no tendency of the organism to reproduce them.

The repetition of an acquired habit for several generations, under the same conditions, may be required to establish it as a dominant character over inherited family traits that have been fixed by transmission through a long line of ancestors, but the final result would show that it had been uniformly transmitted, although it had been for a time obscured by other prevailing hereditary tendencies of the organism.

In discussing the evidence relating to the inheritance of acquired characters, or the effects of use and disuse, these antagonisms in hereditary tendencies should not be lost sight of, as the immediate results looked for may be obscured for a time by other predominant influences.

The development of the improved breeds of live stock furnish abundant evidence of the inheritance of acquired characters, but the limits of this paper will only permit a passing notice of its significance. The most successful breeders of domestic animals have acted on the principle that habits of the organs of nutrition which determine the expenditure of the available energy of foods in a special direction, may be cultivated and intensified by persistent exercise for a number of generations, and it is difficult to explain how the gradual improvement of the desired qualities are obtained without the transmission of the modified habit.

The capacity to fatten at an early age, or, for abundant milk production is promoted by liberal feeding in connection with a judicious exercise of the desired habit of the system, and the highest excellence is obtained when the system of management in each generation is especially directed to the cultivation of the habit in its integrity. This is particularly noticeable in the habit of milk production for a more or less extended period in the course of the year. The fashion of raising lambs by nurses of other breeds, and drying up the dam at once to keep her in show condition, resulted in seriously diminishing the inherited capacity for milk production in the females of the family so treated. It is well known to farmers that cows on short pastures and under careless management will form the habit of "going dry" early in the season, and that this habit of giving milk for a short period is not only transmitted but becomes a marked peculiarity of the females of the family, that is persisted in under better conditions of food supply.

It appears to be unnecessary to assume fortuitous changes in the germ cells to account for the increase, or the suspension of functions that can be so clearly traced to an acquired ancestral habit. Morphological peculiarities are not the only ones that give character to an organism and determine its significant qualities. As in isomeric compounds in chemistry, we find living organisms that are, so far as we can determine, morphologically identical, that differ widely in their habits and general properties. Even in the higher animals the same organ may perform a variety of functions, as the liver for example, and the dominant function for the time being seems to be determined by the requirements of other organs, or of the general system under the special conditions in which it is placed.

There are many species of microbes having the same form and structure that are distinguished by their habits, or the katastates formed in their processes of metabolism, and these katabolic products known as toxines, tox-albumins, and ptomaines, &c., differ widely in their specific properties. Peculiarities in the functional activity of certain organs, or of the general system, appear to be transmitted with the same uniformity and certainty as morphological characters that are more readily observed, although not more significant as distinguishing characteristics.

The experiments of Dr. Dallinger with three species of monads, under prescribed conditions of temperature are of particular interest in showing that the modified or acquired habits of organisms are beyond question transmitted to their offspring. From the rapid repetition of the process of reproduction in these organisms, by fission and sexual fusion, they have marked advantages in experiments for determining the inheritance of new characters.

Throughout the experiments an abundant supply of suitable food was provided, and beginning with a temperature of 60°, which appeared to be the most favorable for them, a gradual increase of temperature was made from time to time as they were able to endure it, until a final temperature of 158° was reached, in the course of seven years, at which there appeared to be a perfect adjustment of their vital activities to the abnormal environment.

There were critical periods as the temperature was increased, at which a considerable time was required for the organisms to become fully acclimated, and when this was secured, a more rapid increase of temperature was for a time admissable, until another point was reached at which a further rise in temperature could not for some time be made.

No advance was possible for eight months after the temperature of 78° was reached; at 93° a halt of nine months was required; and at 137° a further increase of temperature was not permitted until after twelve months had elapsed. The manner in which the organisms were affected at the critical periods will be sufficiently illustrated by Dr. Dallinger's remarks on their behavior at 137°. He says, "when the 136th degree had been passed there were symptoms of oppression and distress, and on touching 137° this was very manifest," and it was found necessary "to play the thermal point backwards and forwards for three weeks before there was an approach to normal activity and fecundity." At the close of the 12 months, during which the temperature was maintained at 137°, there was an increase in the vacuolation of the protoplasm, which disappeared on raising the temperature 4° in the following month. From this time more rapid progress was made until the final temperature of 158° was reached, when the experiment was terminated by an accident to the apparatus.

At times a slight increase of temperature was not tolerated until the changed habits of their protoplasm provided for the complete adjustment of their vital activities to the new environment, but when this adaptation was fully attained there was apparently developed an increased flexibility of their organization that enabled them for a time to bear a comparatively rapid rise of temperature without any perceptible discomfort, but a limit to this toleration was again soon reached. The organisms that had been trained to live at a temperature of 158° with apparent satisfaction, and exhibiting a normal exercise of their nutritive and reproductive functions, were however killed when subjected to a temperature of 60°, which was the most favorable for their ancestors.

The acquired habit of adjusting their physiological activities to an abnormally high temperature was undoubtedly transmitted through many thousand generations, and it is evident that the germ plasma was affected by the changes in the environment, either directly, or with greater probability through the modified metabolism of the body plasma.

These experiments clearly indicate the importance of time, in some species at least, as a factor in the complete adjustment of even functional activities to changes in the environment. Seven years of persistent effort was required to bring about a change in the habits, or metabolic processes of these organisms that enabled them to endure, or actually enjoy, the final temperature of 158°, and a much longer time was evidently needed to produce any marked morphological changes.

The transformations of energy in the metabolic processes of nutrition appear to be probable causes of variation, and possible factors in evolution that require investigation. The effects of use and disuse are not obvious in many organs of an obscure nature and undetermined function, some of which may have intimate relations with the dynamic factors of nutrition, and thus serve a useful purpose which we are now unable to perceive.

What are the relations of the so-called ductless glands, like the thyroid and the supra-renal capsules, to the utilization and conservation of energy? Are not the polar bodies of the ovum, and the thymus of the embryo temporary organs to transfer and conserve energy under special conditions that disappear at later stages of development?

What molecular, or other changes take place in the organism to bring about an intense activity of special functions, involving a more complete utilization of energy, as in increased milk production, or in improved fattening qualities?

Questions like these must be answered, to furnish a satisfactory explanation of biological activities, and theories of nutrition and heredity in which energy is not recognized as one of the prime factors in every vital process should be received with caution, and the fallacious arguments based upon them estimated at their real value.